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(54) **METHOD AND ARRANGEMENT FOR THE ANALYSIS OF GAS CHARACTERISTICS**

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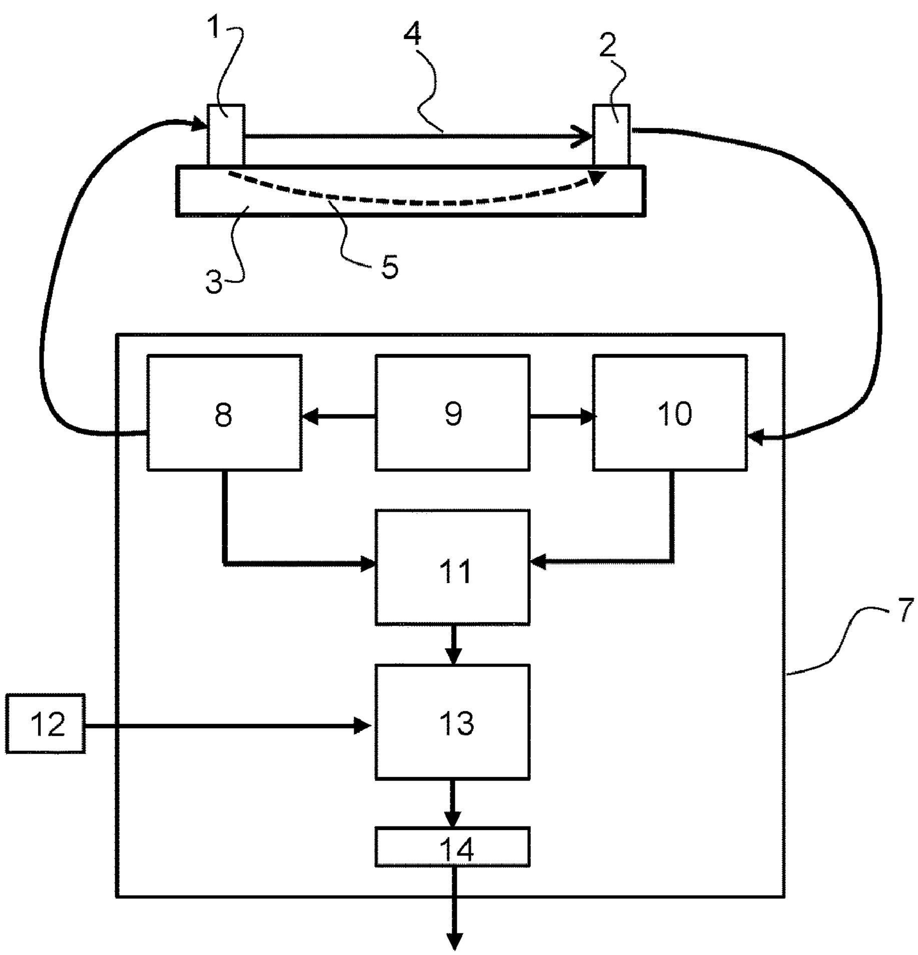
(57) **ABSTRACT**

Detection of gas characteristics, especially the detection of the gas composition, the temperature and/or humidity of a gas, by measuring the speed of sound with a sound sender and a sound receiver both mounted on common structure. A method for determining the humidity of the scavenge air of an internal combustion engine. A speed of sound based gas sensor arrangement adapted to measure gas characteristics, especially the gas composition, the temperature and/or the humidity of a gas, including a sender, a receiver and a signal processing unit. The speed of sound is determined by driving the sender and receiver at different operation cycles in order to differentiate between the different travel times of the sound through the gas and the common structure of solid material.



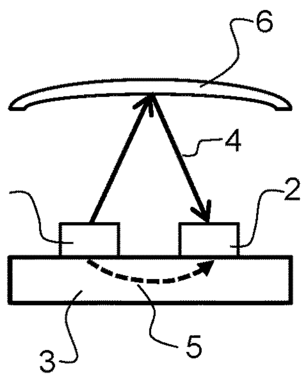


Fig.1

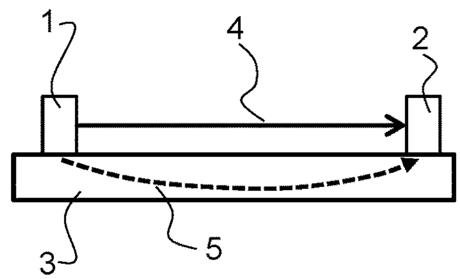


Fig.2

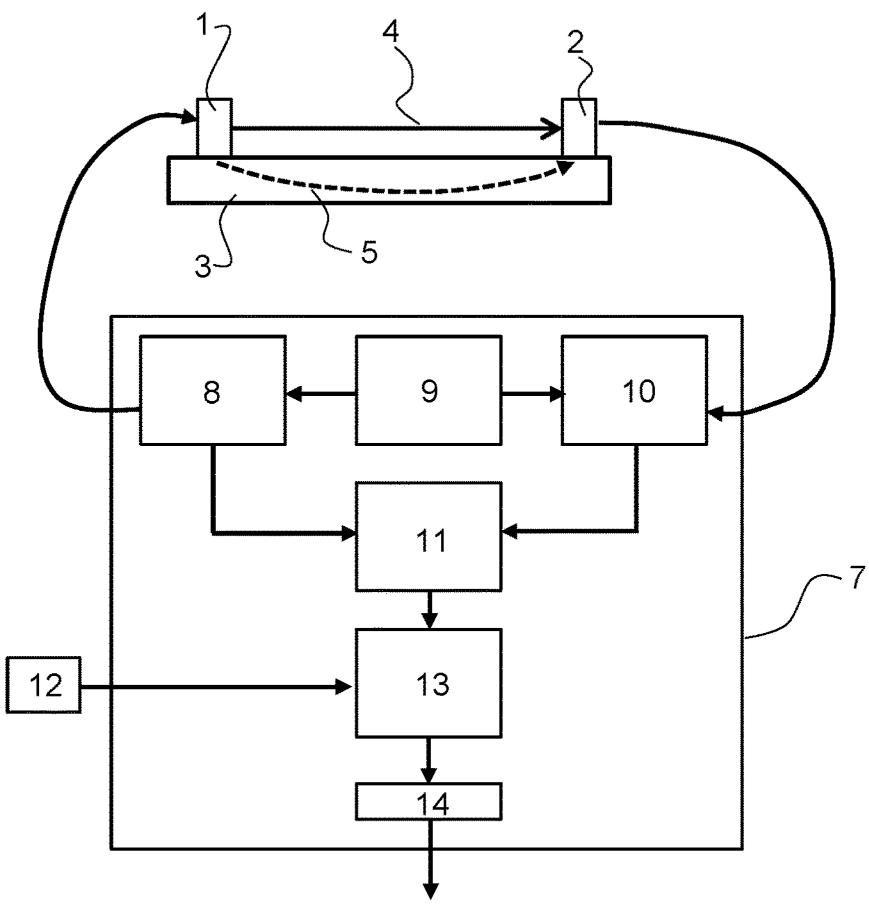


Fig.3

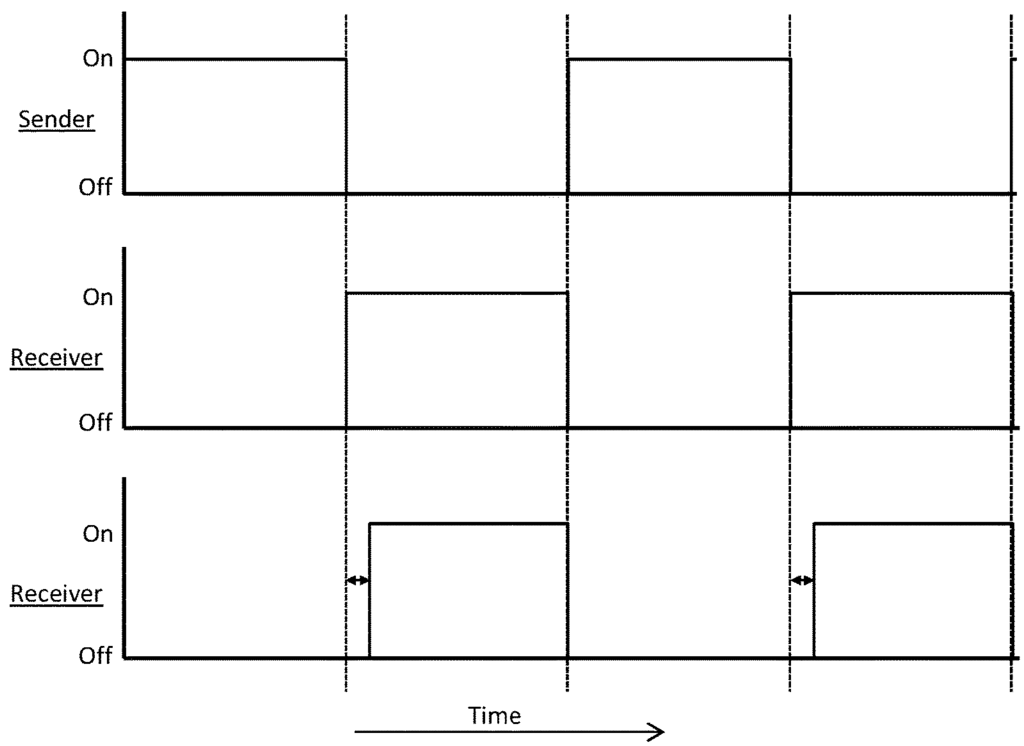


Fig.4

METHOD AND ARRANGEMENT FOR THE ANALYSIS OF GAS CHARACTERISTICS

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application is based upon and claims the benefit of priority of European Patent Application No. 16 178 813.8, filed on Jul. 11, 2016, the entire content of which is incorporated herein by reference.

TECHNICAL FIELD

[0002] The present invention concerns the detection of gas characteristics, especially the detection of the gas composition, the temperature and/or humidity of a gas, by measuring the speed of sound with a sound sender and a sound receiver both mounted on a common structure. The present invention further concerns a method for determining the humidity of the scavenge air of an internal combustion engine. The invention further concerns a speed of sound based gas sensor arrangement adapted to measure gas characteristics, especially the gas composition, the temperature and/or the humidity of a gas, comprising a sender, a receiver and a signal processing unit.

BACKGROUND ART

[0003] It is well known to use the speed of sound in a gas for measuring its temperature/humidity or its composition since the speed of sound is only influenced by its temperature and its composition. Measuring the speed of sound can therefore yield the temperature for a gas with known composition, or the composition of a gas at the known temperature. The measurement can be performed with ultrasonic sound or non-ultrasonic sound. Thus, the term "sound" includes both kinds of sound. If the temperature of the gas is known, it is also possible to determine the humidity. The speed of sound is usually measured by determining the time that an acoustic signal needs to travel the distance between a sender and a receiver. This can be done by sending pulsed signals and measuring the delay for the signal to be detected at the receiver, or by sending a continuous signal and measuring the phase angle between the excitation of the sender and the signal of the receiver.

[0004] For certain sensing applications it is advantageous to mount sender and receiver onto a common structure in order to obtain a self-contained sensor. Sender and receiver can be mounted face by face or in parallel, with the sound traveling via a reflector from the sender to the receiver. In such a case, that common structure will transmit part of the sound energy directly from the sender to the receiver without passing through the measurement gas. Due to the large speed of sound in solids, especially metals, the wavelength of sound in solids is about one order of magnitude larger than in gas, so that the sound travelling via the structure has a different phase angle at the receiver than the sound traveling by the gas. Typically, the variation of the speed of sound with temperature in a solid is relatively small compared to the speed of sound in a gas, and is of the opposite sign.

[0005] As both the structure-borne and the gas-borne sound are of the same frequency, the receiver will produce a signal of which the amplitude and phase are composed of both components. Without additional information, it is therefore not possible to separate the gas-borne signal.

[0006] As long as the structure-borne amplitude is less than a few percent of the total sound amplitude at the receiver, its effect on the quality of the measurement is low. However, notably when both transducers are mounted close together in parallel, the amplitude of the structure-borne sound is significant. It can be reduced by mechanical means, i.e. a construction of the structure which limits and/or damps sound transmission. However, such a mechanical solution is expensive and/or poses problems at elevated temperatures.

[0007] Therefore it is an object of the present invention to propose another possibility to measure the speed of sound in a gas for the detection of gas characteristics, especially temperature and/or humidity, using a sender and a receiver both mounted on a common structure, which avoids the above mentioned drawbacks.

[0008] This object is solved according to the method for measuring the speed of sound and speed of sound-based gas sensor arrangement described herein.

SUMMARY

[0009] According to the invention, structure-borne sound influence on the speed of sound measurements is suppressed by a signal separation in time. The method comprises the following features:

- [0010] providing a structure having a speed of sound which is higher than the speed of sound in the gas,
- [0011] arranging the sender and the receiver on that structure,
- [0012] operating the sender during at least one period of time in an "on"-status such that the sender sends an acoustical signal and operating the sender during at least one period of time in an "off"-status such that the sender does not send an acoustical signal,
- [0013] operating the receiver in an "off"-status for at least one period of time during the "on"-status of the sender and operating the receiver in an "on"-status for at least one period of time during the "off"-status of the sender,
- [0014] integrating the signal of the receiver by an amplifier, calculating the speed of sound and determining based on the speed of sound the temperature and/or the humidity of the gas.

[0015] The common structure in general can be made of any solid material which provides a speed of sound which is higher than the speed of sound in the gas. This requirement is fulfilled especially by metal. A preferred material is steel, which has as speed of sound of approximately 4000 m/s. The sender and the receiver on the structure can be arranged in parallel by using an additional reflector, or face to face. By operating the sender in the above mentioned "on"-status whereas at the same time the receiver operates in an "off"-status and vice versa the gas-borne and the structure-borne contributions can be separated in time. In view of the different speed of sound in the different materials, for example, the sender is operated during a first period, while the input from the receiver to the amplifier is switched off. During the next period, which can be different in the duration from the first period, the sender is switched off while the signal of the receiver is measured by the amplifier. As the last structure-borne sound will reach the receiver depending on the speed of sound almost immediately after the sender has been switched off, the structure-borne contribution to the receiver signal will be reduced to a certain amount, which depends on the kind of material and the arrangement of sender and receiver. The structure-borne contribution can be reduced further by introducing a delay of some few microseconds between switching off the sender, and switching on the receiver. Such a delay might be necessary if internal reflections of the sound within the structure delay the transition time of the structure-borne sound.

[0016] As the overall noise level of the measurement strongly depends strongly on the number of over how many signal oscillations the amplifier is able to integrate, the “on” time of the receiver should correspond to the time of travel of the gas-borne sound. For the same reason, the “on” time of the sender should span the same amount of time, so that the duty cycles of sender and receiver are both 50% with a phase shift of 7C. With a lock-in amplifier it is possible to integrate the receiver signal continuously over extended periods of time. The amplitude measured by the lock-in amplifier will be half of a continuous signal, whereas the phase angle information is entirely maintained. In this case, the reference channel between the function generator driving the sender and the lock-in amplifier must be open all the time.

[0017] According to preferred embodiment of the invention, the “on”-status of the receiver starts with a delay after the end of the “on”-status of the sender in case of internal reflections as mentioned above.

[0018] It is also possible that the sender and the receiver are never operated in their respective “on”-status simultaneously or in other words that the sender and the receiver are operated alternately.

[0019] According to another preferred embodiment of the invention the duration of the “on”-status of the receiver corresponds to the travel time of the sound through the gas. The travel time of the sound depends on the distance the sound has to travel between the sender and the receiver and the speed of sound in the gas. By having an “on”-status which corresponds to the travel time, an optimal amount of the signal is available for further determination. Respectively, it is advantageous if the duration of the “on”-status of the sender corresponds to the travel time of the sound through the gas.

[0020] Further, according to another advantageous embodiment the duty cycle in the “on”-status of the receiver and the “on”-status of the sender is maintained with same amount of time for obtaining optimal determination conditions with duty cycles of sender and receiver both being 50% with a phase shift of 7C.

[0021] As mentioned above with the amplifier it is possible to integrate the signal of the receiver over a number of switching periods. In a preferred embodiment the signal of the receiver is integrated by the amplifier over extended periods of time.

[0022] In general it is possible to determine the difference in the travel times or in the phase angle difference between the sender excitation and the receiver signal. According to a preferred embodiment the characteristics of the gas, especially the gas composition, the temperature and/or the humidity, are calculated at least from the phase angle difference between the sender excitation and the receiver signal.

[0023] In order to achieve the necessary come to the separation in time which allows the determination of the variations of the speeds of sound with high resolution according to the first advantageous embodiment, the invention comprises a mechanical structure having a speed of sound being at least five times, preferably ten times, faster than the speed of sound in the gas.

[0024] In another preferred embodiment of the invention the sender and the receiver are arranged on that structure such that the sound emitted by the sender reaches the receiver via an acoustical reflector. This provides a significantly shorter travel path of the structure-borne sound in comparison to sender and receiver being arranged face to face, and therefore facilitates the temporal separation. This is further supported by arranging the sender and the receiver according to a further preferred embodiment within a distance of less than 10 mm preferably in the region of 4 mm.

[0025] A special application of the method described above is the measurement of the humidity of engine scavenge air. For the right stoichiometric fuel rate in an internal combustion engine, most notably large industrial and marine engines, as well as some trucks and heavy machinery, it is necessary to measure the humidity in the scavenge air. In view of the high temperature and pressure in the region between a turbocharger and the combustion chamber, state-of-the-art measurement devices for determining the humidity are influenced by the gas conditions. In view of this, according to the preferred embodiment, the method described before above can be used for adjusting the relationship between intake air and fuel of an internal combustion engine by determining the humidity of the engine scavenge air.

[0026] The speed of sound-based gas sensor arrangement adapted to measure gas characteristics on the basis of the speed of sound, especially the gas composition, the temperature and/or the humidity of a gas, comprises means being adapted to perform the method as claimed and described above.

[0027] Especially, the gas sensor arrangement adapted to measure gas characteristics on the basis of the speed of sound, especially the temperature and/or the humidity of a gas, comprises a sender, a receiver and a signal processing means as known. According to the invention the arrangement comprises a sound sender and an acoustical receiver both mounted on a common structure, wherein the signal processing means operates the sender during a least one period of time in an “on”-status by sending an acoustical signal and during at least one period of time in an “off”-status without sending an acoustical signal, operates the receiver in an “off”-status during at least one period of time of the “on”-status of the sender and in an “on”-status during at least one period of time of the “off”-status of the sender, and integrates the signal of the receiver, calculates the speed of sound and determines based on the speed of sound the gas characteristics such as gas composition, the temperature and/or the humidity of the gas and provides a respective output signal for further treatment.

[0028] According to a preferred embodiment of the speed of sound based gas sensor arrangement the acoustical signal from the sender reaches the receiver via an acoustical reflector, wherein preferably the acoustical reflector is a wall of a pipe, a wall of an air deflector or a wall of a housing of a chamber and that the gas to be measured is within that pipe or chamber.

[0029] With the present invention it is therefore possible to suppress the structure-borne sound influence on a speed of sound measurement with low cost and high stability. This allows to use the method or the arrangement for applications in which the determination of gas characteristics, such as gas composition, temperature and/or humidity was either not possible or did not work with the required sensitivity or accuracy.

[0030] In the following, embodiments of the invention are described in detail in connection with the drawings. However, the invention is not limited to the examples described in connection with the drawings and includes all embodiments covered by the claims and the description alone or in connection with each other.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] The figures show:

[0032] FIG. **1** a principle depiction of a gas sensing arrangement comprising a sender and a receiver on a common structure and reflection means arranged apart from the sender and the receiver such that the sound excited by the sender travels via the reflection means to the receiver through the gas for providing a gas-borne signal,

[0033] FIG. **2** another principle depiction of a gas sensing arrangement comprising a sender and a receiver on a common structure wherein sender and receiver are arranged such that the sound travels directly from the sender to the receiver through the gas between the sender and the receiver for providing a gas-borne signal,

[0034] FIG. **3** the principle depiction of FIG. **2** together with a block diagram of a signal processing unit comprising signal processing means, and

[0035] FIG. **4** a diagram of the cycle times of the sender and the receiver with different receiver cycle times.

DETAILED DESCRIPTION

[0036] The principle of the common structure with the sender and the receiver with or without reflection means can be used in all applications which require a reliable system in extreme environment conditions for systems, such as for example in combustion engine exhaust applications or applications which require measurements across large temperature ranges.

[0037] FIG. **1** shows a mounting structure **3** with a sender **1** and a receiver **2** mounted on that structure **3**. Sender **1** and receiver **2** are mounted such that the sound propagation **4** from the sender **1** to the sender **2** travels via an acoustic reflector **6** before reaching the sender **2**. That sound provides a gas-born signal. The sound propagation **5** of the sound provided by the sender **1** travels via the structure **3** to the receiver **2** thereby providing a structure-born signal.

[0038] FIG. **2** shows a mounting structure **3** in which the sender **1** and the receiver **2** mounted on that structure **3** are arranged in a face to face position wherein the sound propagation **4** is directly from the sender **1** to receiver **2** without a reflector in the sound path. In contrast to the arrangement of FIG. **1**, sender **1** and receiver **2** are arranged with a much larger distance between them. The distance between the sender **1** and receiver **2** in the arrangement according to FIG. **1** is less than 10 mm, preferably around 4 mm, whereas the distance in the arrangement of FIG. **2** is in the order of 50-100 mm. It is important that the propagation times, i.e. time that the sound needs from the sender **1** to the receiver **2** via the different media (gas or solid material), differ significantly in order to determine the speed of sound of the gas after processing the received signals with a sufficient accuracy. Similar to FIG. **1**, the sound traveling directly through the gas from the sender **1** to the receiver **2** provides the gas-borne signal and the sound propagation **5** through the structure from the sender **1** to the receiver **2** provides the structure-borne signal. The acoustical reflector **6** can be a wall of a pipe or a wall of a housing of a chamber and the gas to be measured is within that pipe or chamber (not depicted).

[0039] In FIG. **3** a block diagram is shown depicting a signal processing unit **7** comprising a microprocessor **13** and a sound function generator **8** which provides an ultrasound in this embodiment. The sound function generator **8** is connected with the sender **1**. The receiver **2** is connected with a receiver pre-amplifier/AD-converter **10** of the signal processing unit **7**. The signal processing unit **7** also comprises a switching function generator which controls the sound function generator **8** and the receiver pre-amplifier/AD-converter **10** in view of their duty cycle. The sound function generator **8** is connected with a lock-in amplifier **11** as well as the receiver pre-amplifier/AD-converter **10**. The sound function generator **8** provides the lock-in amplifier **11** with a respective reference signal. The lock-in amplifier **11** determines the phase angle between the reference signal delivered from the sound function generator **8** and the receiver signal from the receiver pre-amplifier/AD-converter **10**. A microprocessor **13** of the signal processing unit **7** reads the output signal from the lock-in amplifier **11** as well as from an external temperature measurement device **12** and provides a humidity value output **14** in form of a respective signal for further processing. In another advantageous embodiment, the lock-in amplifier **11** can be integrated digitally within the microprocessor **13**.

[0040] In an exemplary embodiment, the sender **1** and the receiver **2** as shown in FIG. **1** are mounted very closely (distance of 4 mm) in parallel on the structure **3** made of steel. The sound of speed in steel is approximately 4,000 m/s, which means that any structure-borne sound takes 1 μs to travel from the sender to the receiver.

[0041] Through the gas, the sound will travel via the acoustical reflector **6** over a total distance of 40 mm. With a sound of speed in the gas in the order of 400 m/s, the gas-borne sound takes 100 μs to travel from the sender **1** to the receiver **2**.

[0042] Both contributions can therefore be separated in time as shown in FIG. **4**. In that figure the first diagram shows the duty times of the sender **1** over time. The second and middle diagram shows the duty time of the receiver **2** without delay with respect to "on"-status of the sender **1**, whereas in the third and lowest diagram shows the duty time of the receiver **2** is delayed in respect to the shut-off of the sender **1**. In the above example with the mentioned dimensions and material, the sender **1** is operated during 100 μs, while the input from the receiver **2** to the amplifier **10** is switched off. During the next 100 μs, the sender **1** is switched off while the signal of the receiver **2** is measured by the amplifier **10**. As the last structure-borne sound will reach the receiver **2** 1 μs after the sender **1** has been switched off, the structure-borne contribution to the receiver signal has been reduced to 1%, if both contributions have the same amplitude. The structure-borne contribution can be reduced further by introducing a delay of some few microseconds between switching off the sender **1**, and switching on the receiver **2** as shown in the lowest diagram of FIG. **4**. Such a delay might be necessary if internal reflections of the sound within the structure **3** delay the transition time of the structure-borne sound.

[0043] As the overall noise level of the measurement strongly depends on over how many signal oscillations the amplifier can integrate, the << on >> time of the receiver **2** should correspond to the time of travel of the gas-borne sound. For the same reason, the << on >> time of the sender **1** should span the same amount of time, so that the duty cycles of sender **1** and receiver **2** are both 50% with a phase shift of 7C.

[0044] At an operational frequency of 50 kHz, the amplifier **11** will therefore integrate the receiver's signal over 5 periods. However, with a lock-in amplifier **11** as used it is possible to integrate the receiver signal continuously over extended periods of time. The amplitude measured by the lock-in amplifier **11** will be half of a continuous signal, whereas the phase angle information is entirely maintained. In this case, the function generator **8** driving the sender **1** must supply a reference signal to the lock-in amplifier **11** all the time.

1. A method for measuring a speed of sound in a gas for detection of gas characteristics, with a sound sender and a sound receiver both mounted on a common structure, comprising:

providing the structure having a speed of sound which is higher than the speed of sound in the gas,

arranging the sender and the receiver on the structure,

operating the sender during at least one period of time in an "on"-status such that the sender sends an acoustical signal and operating the sender during at least one period of time in an "off"-status such that the sender does not send an acoustical signal,

operating the receiver in an "off"-status for at least one period of time during the "on"-status of the sender and operating the receiver in an "on"-status for at least one period of time during the "off"-status of the sender,

integrating the signal of the receiver by an amplifier, calculating the speed of sound and determining based on the speed of sound the said characteristics of the gas.

2. The method according to claim **1**, comprising starting the "on"-status of the receiver with a delay after the end of the "on"-status of the sender.

3. The method according to claim **1**, wherein the duration of the "on"-status of the receiver corresponds to the travel time of the sound from the sender to the receiver through the gas and/or the duration of the "on"-status of the sender corresponds to the travel time of the sound from the sender to the receiver through the gas.

4. The method according to claim **1**, comprising integrating the signal of the receiver by the amplifier over extended periods of time.

5. The method according to claim **1**, comprising calculating the characteristics of the gas from the phase angle difference between the sender excitation and the receiver signal.

6. The method according to claim **1**, comprising providing a mechanical structure having a speed of sound being at least five times higher than the speed of sound in the gas.

7. The method according to claim **1**, comprising arranging the sender and the receiver on that structure such that the sound emitted by the sender reaches the receiver via an acoustical reflector.

8. The method according to claim **1**, comprising arranging the sender and the receiver within a distance of less than 10 mm.

9. A method comprising determining humidity of an engine scavenge air using the method of claim **1**.

10. A speed of sound based gas sensor arrangement adapted to measure gas characteristics according to the method as recited in claim **1**.

11. A speed of sound based gas sensor arrangement adapted to measure gas characteristics, comprising a sound sender, an acoustical receiver and a signal processing means, wherein the sound sender and the acoustical receiver are both mounted on a common structure, wherein the signal processing means operates the sender for at least one period of time in an "on"-status such that the sender sends an acoustical signal and the signal processing means operates the receiver for at least one period of time in an "off"-status such that the sender does not send an acoustical signal, wherein the signal processing means operates the receiver in an "off"-status for at least one period of time during the "on"-status of the sender and in an "on"-status for at least one period of time during the "off"-status of the sender, and wherein the signal processing means, especially a microprocessor of the signal processing means, integrates the signal of the receiver, calculates the speed of sound and determines based on the speed of sound gas characteristics and provides a respective output signal.

12. The speed of sound based gas sensor arrangement according to claim **11**, wherein the acoustical signal from the sender reaches the receiver via an acoustical reflector, wherein the acoustical reflector is a wall of a pipe or a wall of a housing of a chamber and that the gas to be measured is within that pipe or chamber.

13. The speed of sound based gas sensor arrangement according to claim **11**, wherein the sound sender and the acoustical receiver are both mounted side by side on the common structure within a distance of less than 10 mm.

14. The speed of sound based gas sensor arrangement according to claim **11**, wherein the measured gas characteristics is at least one of gas composition, humidity and temperature.

15. The method according to claim **1**, wherein the measured gas characteristics is at least one of gas composition, humidity and temperature.

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